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Red-light cameras for the prevention of road traffic crashes (Review)

Aeron-Thomas A, Hess S

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[Intervention Review]

Red-light cameras for the prevention of road traffic crashes

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ABSTRACT

Background

Road crashes are a prime cause of death and disability and red-light running is a common cause of crashes at signalised intersections. Red-light cameras are increasingly used to promote compliance with traffic signals. Manual enforcement methods are resource intensive and high risk, whereas red-light cameras can operate 24 hours a day and do not involve high-speed pursuits.

Objectives

To quantify the impact of red-light cameras on the incidence and severity of road crashes and casualties, and the incidence of red-light violations.

Search methods

We searched the following electronic databases: TRANSPORT (NTIS, TRIS, IRRD,TRANSDOC), Cochrane Injuries Group Specialised Register, Cochrane Controlled Trials Register, MEDLINE, EMBASE and the Australian Transport Index. We checked the reference lists of relevant papers and contacted research and advocacy organisations.

Selection criteria

Randomised or quasi-controlled trials and controlled before-after studies of red-light cameras. For crash impact evaluation, the before and after periods each had to be at least one year in length. For violation studies, the after period had to occur at least one year after camera installation.

Data collection and analysis

Two reviewers independently extracted data on study type, characteristics of camera and control areas, and data collection period. Before-after data were collected on number of crashes by severity, collision type, deaths and injuries, and red-light violations. Rate ratio was calculated for each study. Where there was more than one, rate ratios were pooled to give an overall estimate, using a generic inverse variance method and a random-effects model.

Main results

No randomised controlled trials were identified but 10 controlled before-after studies from Australia, Singapore and the USA met our inclusion criteria. We grouped them according to the extent to which they adjusted for regression to the mean (RTM) and spillover effects. *Total casualty crashes:* the only study that adjusted for both reported a rate ratio of 0.71 (95% CI to 0.55, 0.93); for three that partially adjusted for RTM but failed to consider spillover, rate ratio was 0.87 (95% CI to 0.77, 0.98); one that made no adjustments had a rate ratio of 0.80 (95% CI 0.58 to 1.12). *Right-angle casualty crashes*: rate ratio for two studies that partially addressed RTM was 0.76 (95% CI 0.54 to 1.07). *Total crashes*: the study addressing both RTM and spillover reported a rate ratio of 0.93 (95% CI 0.83 to 1.05); one study that partially addressed RTM had a rate ratio of 0.92 (95% CI 0.73 to 1.15); the pooled rate ratio from the five studies with no adjustments was 0.74 (95% CI 0.53 to 1.03). *Red-light violations*: one study found a rate ratio of 0.53 (95% CI 0.17 to 1.66).

Authors' conclusions

Red-light cameras are effective in reducing total casualty crashes. The evidence is less conclusive on total collisions, specific casualty collision types and violations, where reductions achieved could be explained by the play of chance. Most evaluations did not adjust for RTM or spillover, affecting their accuracy. Larger and better controlled studies are needed.

PLAIN LANGUAGE SUMMARY

'Red-light cameras' cut casualty crashes at junctions with traffic lights

Road crashes are a leading cause of death and injury. One common place for these to happen is at junctions (intersections) controlled by traffic signals. 'Red-light cameras' are now widely used to identify drivers that jump ('run') red lights, who can then be prosecuted. This review looked for studies of their effectiveness in reducing the number of times that drivers drive through red lights and the number of crashes. Very little research has been done and much of it has not allowed for the statistical problems that occur when recording this kind of information. However, five studies in Australia, Singapore and the USA all found that use of red-light cameras cut the number of crashes in which there were injuries. In the best conducted of these studies, the reduction was nearly 30%. More research is needed to determine best practice for red-light camera programmes, including how camera sites are selected, signing policies, publicity programmes and penalties.

BACKGROUND

Road crashes are a leading cause of death and disability. The most common victim is a man in the prime of life, most likely with family dependants. Road deaths and injuries are expected to increase for at least the next two decades and, by 2020, road traffic injury is predicted to become the third greatest cause of death and disability in the world. Traffic injury will then follow heart disease and depression − conditions as slow in their development as injury is sudden (WHO 2004).

Motorisation is increasing even faster than road death and injury (Jacobs 2000). Many low-income countries have experienced rapid growth in their motor vehicle fleet, especially in motorcycles, the most vulnerable of all motorised modes. With motorisation comes the need for traffic control and signalisation of junctions. Drivers running ('jumping') red lights are a leading cause of crashes at signalised junctions. While most of these crashes are 'damage only', many can be serious, as speed and side impacts are often involved (TRB 2003).

Red-light cameras are increasingly used to enforce compliance with traffic signals. Traditional manual enforcement methods are both resource intensive and high risk, whereas red-light cameras have the advantage of operating 24 hours a day and do not involve high-speed pursuits. Red-light cameras, unlike the police, are also immune from charges of discrimination, as they detect only those vehicles that have violated a traffic signal. The prevention of right-angle collisions is regarded as the prime target in red-light cameras programmes, as other crashes (i.e. rear-end collisions) carry a lower risk of causing serious injury.

Red-light cameras have been in use since the early 1970s and much has been written on their operation. Nevertheless, several recent syntheses and meta-analyses of red-light camera programmes have commented on the methodological weaknesses of the evaluations of their effectiveness that have so far been conducted (ICBC 2004, TRB 2003, Retting 2003, Flannery 2002). This review analyses the evidence available on the safety benefits of red-light cameras.

OBJECTIVES

To quantify the impact of red-light cameras on the incidence and severity of road crashes and casualties, as well as on the incidence of red-light violations.

METHODS

Criteria for considering studies for this review

Types of studies

Studies were included if they involved one of the following research designs:

- randomised or quasi controlled trial (RCT);
- controlled before-and-after study (CBA).

Definitions were based on those used by the Cochrane Effective Practice and Organisation of Care group as given below.

- RCT: A study involving at least one test and one control treatment, concurrent enrolment and follow-up of the test and control-treated groups, and in which the treatments to be administered are selected by a random process. If the author(s) state explicitly (usually by using some variant of the term 'random' to describe the allocation procedure used) that the groups compared in the trial were established by random allocation, then the trial is classified as 'RCT'.
- Quasi-RCT: Treatment allocations using odd-even numbers, days of the week, or other pseudo- or quasi-random processes, are not truly randomised and a study employing any of these techniques for assignment is designated as quasi-randomised.
- CBA: A design where there is contemporaneous data collection before-and-after the intervention and an appropriate control site or activity.

The before and the after periods had to be at least 12 months each, while for violation studies the after period had to occur at least one year after camera installation.

Types of participants

- all road users;
- intersections and areas assigned red-light cameras.

Types of interventions

Cameras used at intersections to detect red-light violators (offenders), so that they might be charged with their offences. We have included both junctions equipped with cameras and area-wide programmes where cameras operate at some of the signalised junctions.

Types of outcome measures

Primary outcomes

- road traffic casualties and crashes, by severity, at both camera sites and in camera areas

Secondary outcomes

- red-light violations, by the number of drivers/vehicles passing through red lights after entering on red (i.e. not amber).

Search methods for identification of studies

Electronic searches

The following electronic databases were searched:

- Cochrane Injuries Group's Specialised Register;
- Cochrane Controlled Trials Register;
- MEDLINE;
- EMBASE;
- TRANSPORT - includes databases from the Transportation Research Board (Transport Research Information Services [TRIS]), from the Organisation for Economic Co-operation and Development (International Road Research Documentation [IRRD]) and from the European Ministers of Transport (TRANSDOC);
- ATRI (Australian Transport Research Institute);
- SPECTR (Social Psychological Evaluative Controlled Trial Research).

For information on search strategy terms, see Appendix 1.

The following websites were also searched:

- AAA Foundation for Traffic Safety, USA - www.aaafoundation.org;
- Australian Road Research Board (ARRB) - www.arrb.org.au;
- Australian Transport Safety Bureau - www.atsb.gov.au;
- Information and Technology Centres for Transport and Infrastructure (CROW), Netherlands - www.crow.nl;
- Danish Council for Road Safety Research - www.trm.dk/eng/veje/rft;
- Danish Transport Research Institute - www.dtf.dk;
- Department for Transport (DfT), UK - www.dft.gov.uk/;
- Deutscher Verkenrssichereitsrat Road Safety Institute (DVR), Germany - www.dvr.de/;
- European Transport Safety Council (ETSC) - www.etsc.be;
- Finnish National Road Administration (FINNRA) - www.tieh.fi;
- Institut National de Recherche sur les Transports et leur Sécurité (INRTES), France - www.inrets.fr;
- Institute of Transportation Engineers (ITE), USA - www.ite.org;
- Laboratoire d'economie des transports (LET), France - www.lsh-lyon.cnrs.fr;
- National Highway Traffic Safety Administration (NHTSA), USA - www.nhtsa.dot.gov;
- Swedish National Roads Administration - www.vv.se/for_lang/english/;
- Institute for Road Safety Research (SWOV), Netherlands - www.swov.nl;
- Institute of Transport Economics (TOI), Norway - www.toi.no;
- Transport Canada (TC) - www.tc.gov;
- Transportation Research Board (TRB), USA - www.nas.edu/trb/;
- Transport Research Laboratory (TRL), UK - www.trl.co.uk;
- US Department of Transport - Federal Highway Administration (FHWA)- www.fhwa.dot.gov;
- Swedish National Road and Transport Research Institute (VTI) - www.vti.se;
- Technical Research Centre, (VTT), Finland - www.vtt.fi/indexe.htm;
- Centres for Disease Control (CDC), USA - www.cdc.gov/;
- World Health Organization (WHO) - www.who.org.

UK Safety Camera Partnership websites were also searched and red-light camera advocacy organisations in the US and Canada were contacted. In addition to the websites listed above, key European road safety organisations – e.g. ETSC, TISPOL (European Traffic Police Network) – were contacted in order to try and identify published or soon to be published red-light camera evaluations.

Data collection and analysis

Selection of studies

Two reviewers independently examined titles, abstracts and keywords of citations, as given on electronic databases, for study eligibility and decided whether studies met the inclusion criteria.

Data extraction and management

Two reviewers independently extracted data from the selected studies. Data sought included the type of study, selection process and characteristics of camera and control areas, duration and date of before/after periods, camera signing practices, associated publicity campaigns and penalties, outcomes evaluated, and the extent to which the study controlled for other factors such as seasonal variation and traffic flows. Where necessary, study authors were contacted for clarification.

Assessment of risk of bias in included studies

The included studies were assessed on whether they had adjusted for two key and common weaknesses: regression to the mean (RTM) and spillover effects.

- RTM is a statistical phenomenon that occurs when there is non-random, biased selection of sites. As most safety engineering remedial measures are introduced at sites with the highest number of collisions, these locations can be expected to experience lower collision rates in the after period, even without the introduction of a safety measure, due to the natural tendency to regress towards the mean. RTM can be avoided by using a randomised trial or adjusted for with a statistical method, e.g. the empirical Bayesian method.
- As red-light camera programmes involve publicity campaigns and warning signs, behaviour in general may be influenced, with drivers inclined to obey red lights at all signalised junctions thus reducing the risk of collisions at non-camera sites. To control for this spillover effect, control sites should be located away from red-light camera sites and the associated publicity.

Three basic categories were used: adjusted studies that addressed both RTM and spillover effects; partially adjusted studies that addressed RTM but not spillover effects; and the remaining studies that did not adjust for either of these factors.

Data synthesis

A weighted intervention effect was calculated across trials, using the statistical facility in Cochrane's RevMan software. The results for dichotomous outcomes were expressed as rate ratio and 95% confidence intervals (CIs). The rate ratio is the ratio of event rates post and pre-intervention in the intervention area divided by the corresponding post to pre-intervention ratio in the control area. Assuming that any changes to the population at risk in the intervention area is the same as that in the control area, the rate ratio shows the reduction in the incidence rate in the intervention area to that predicted from the rates in the control area. Thus a rate ratio of 0.7 indicates a 30% reduction in events compared to that predicted from the rates in the control area.

Standard errors for logarithms of rate ratios, and hence 95% CIs for rate ratios, were calculated assuming that the number of events in each area in each period followed a Poisson distribution. The generic inverse variance method was used with a random effects meta-analysis model. Heterogeneity between studies was evaluated using a chi-squared test; there was considered to be significant heterogeneity when P was less than or equal to 0.05.

RESULTS

Description of studies

The initial searching identified 599 published articles but not all referred to red-light cameras for traffic enforcement. After further screening, 30 studies were considered in detail but 20 were subsequently excluded. No randomised controlled trials were found but there were 10 controlled before-after studies that met the inclusion criteria.

Despite the increasing use of red-light cameras, very few controlled before-after evaluations of red-light cameras were identified. There were, for example, none from the UK, where red-light cameras were introduced in 1991. The first four studies were from Australia and Singapore. The first three were in Australia (1988 to 1994) and involved the rotation of red-light cameras among camera sites (South Melbourne 1988; Hillier Sydney 1993; Mann Adelaide 1994). The Singapore study evaluated fixed red-light cameras, with some of the junctions having cameras assigned to multiple approaches (Ng Singapore 1997).

After 1997, the only studies found were from the US, where red-light cameras were first introduced in 1993. Two studies (Retting Fairfax 1999; Retting Oxnard 2002) included a comparison with non-cameras sites within the same locality, as well as a comparison with other nearby cities that did not have red-light cameras. The California Bureau of State Audit recently reviewed red-light camera programmes and compared red-light camera junctions to all other intersections within the locality (CA SA LA 2002; CA SA Oxnard 2002; CA SA S'mento 2002; CA SA San Diego 2002).

Nine studies evaluated the impact on crashes, while one reported red-light violations (Retting Fairfax 1999). Crash statistics were collected from official databases based on police reports, while violations were monitored by video camera and red-light camera. No studies reported on fatal or serious injury collisions but five studies investigated the effect on total casualty crashes (South Melbourne 1988; Hillier Sydney 1993; Mann Adelaide 1994; Ng Singapore 1997; Retting Oxnard 2002), which include fatal, serious and slight injury crashes.

Four studies reported rear-end casualty crashes (South Melbourne 1988, Hillier Sydney 1993, Mann Adelaide 1994, Ng Singapore 1997). Three studies monitored right-angle casualty crashes (South Melbourne 1988, Mann Adelaide 1994, Ng Singapore 1997), while two studies reported the effect on total casualties (South Melbourne 1988, Mann Adelaide 1994).

Seven studies evaluated the impact on total crashes, including property damage-only crashes (Hillier Sydney 1993, Mann Adelaide 1994, Retting Oxnard 2002, CA SA LA 2002, CA SA Oxnard 2002, CA SA S'mento 2002, CA SA San Diego 2002).

Two studies (Hillier Sydney 1993, Mann Adelaide 1994) evaluated the impact on all right-angle crashes (including damage-only crashes) and all rear-end crashes (including damage-only crashes), as well as damage-only crashes for both collision types and total damage-only crashes. One study reported the impact on damage-only, right-angle, rear-end and right-turning damage-only crashes (Mann Adelaide 1994).

Risk of bias in included studies

The included studies are organised below into three categories: studies that accounted for RTM and spillover effect, those that attempted to adjust for either RTM or the spillover effect, and those that made no adjustments at all. In addition to summarising the camera and control site selection criteria, the Table of included studies also includes information on the number of cameras and control sites, the length of the before-after periods and information relevant to performance bias (extent to which cameras were signed and/or publicised).

Adjusted studies

Retting Oxnard 2002
A controlled before-after study in Oxnard, California, USA of the impact of red-light cameras on road crashes, where four red-light cameras were rotated on single approaches at 11 of the 125 signalised intersections. The before period of 29 months and an after period of 20 months were separated by a two-month gap. Camera sites were chosen on the basis of red-light related crash data, technical suitability, and informal input. The impact was measured in terms of all signalised junctions in Oxnard, which avoided the problem of RTM. Comparison was made with the non-signalised junctions in Oxnard and three other cities in California of varying proximity (one 40 miles and two 100 miles away) in order to adjust for any spillover effect. These cities all had approximately the same number of crashes as did Oxnard. Results were reported on total crashes (including property damage) and total casualty crashes at both signalised and non-signalised junctions, excluding those intersections that were signalised during the survey period.

Partially adjusted studies

South Melbourne 1988
A controlled before-after study conducted in Melbourne, Australia, with a three-year before and three-year after period. The worst 100 signalised junctions (in terms of total right-angle and right-angle casualty crashes during 1977 to 1981) were divided into treatment and control sites. Camera and control sites were alternated on major roads. Adjacent intersections were not included in the trial and sites were allocated so that, where possible, treatment sites were located next to control sites. Control sites were chosen to be as similar as possible, in terms of high collision rates, speed limits and junction configuration, (e.g. single-lane and double-lane approaches, intersections with medians, tram lines, different speed limits). While all camera sites had warning signs posted, only a minority were active at any one time with between seven and ten red-light cameras rotated among the 46 camera sites. Results were reported separately on casualty crashes (including total, right-angle, rear-end, right-angle turning, right-against, and rear-end turning) and total casualties.

Hillier Sydney 1993
A controlled before-after study in Sydney, Australia with a two-year before and two-year after period, separated by a gap of 18 months. Camera sites (16) were allocated into two groups: 'most-used' and 'least-used', according to the amount of red-light camera allocation time. Little information was provided on the rotation of the six cameras used. All camera sites were signed. Two control groups were chosen on the basis of crash history, traffic volume and junction configuration, although the least used control site group was dropped after it received other interventions. Results were reported separately for casualty and total crashes, including damage-only (total, right-angle, rear-end), as well as for fatal and injury crashes.

Ng Singapore 1997
A controlled before-after study in Singapore, where 42 camera junctions were compared with 42 control junctions. A three-year before and a three-year after period were used. Camera sites were chosen on the basis of the incidence of high occurrence of collisions and/or violations, hazards from heavy traffic flows, and complaints

by pedestrians. Warning signs were installed at camera sites. Singapore has a high number of red-light cameras with cameras at one-fifth of all signalised junctions. Some junctions had cameras on as many as three approaches. Control sites were selected on the basis of a high collision record and similar layout. Difficulties in identifying control sites were reported. Traffic volumes and mixes were assumed to be similar and so were not taken into consideration. Results were presented on casualty crashes only (total, right-angle, rear-end, head-on/sideswipe and other crashes).

Retting Fairfax 1999
A controlled before-after study in Fairfax, Virginia, USA of the impact on red-light violations by five (single-approach) red-light cameras. The before survey was conducted immediately before the red-light camera warning period. After surveys were taken three and 12 months afterwards (daytime hours only at control sites). The number of exposure hours in each of the before-after periods ranged from 113 to 117 hours for the camera sites and 71 to 72 hours for the control sites outside of Fairfax. Camera sites were selected on the basis of collision history, and included three cameras installed in 1997 and two in 1998. Control sites were chosen both within Fairfax and in near-by counties, to control for such factors as weather, seasonal variability, traffic pattern and a spillover effect. The comparison between Fairfax and the nearby counties is reported in this review.

No adjustments

Mann Adelaide 1994
A controlled before-after study in Adelaide, Australia with five red-light cameras rotated amongst 15 junctions, chosen on the basis of their crash record and high traffic flows. Control sites included 14 signalised junctions, selected on the basis of high traffic volumes, similar geometrics, and a similar share of inner city sites. The before and after periods were five years each. Warning signs were posted at all approaches to camera junctions and the amber phase was increased from three to four seconds at the start of the red-light camera programme. Results were reported separately for casualty and property damage-only collisions (total, right-angle, rear-end and right-turn crashes).

The following four studies were all reported in a recent California State Audit Bureau report. As required by state law, all red-light camera sites had to have a public hearing, public notice and 30-day warning period before camera enforcement began. California is also the only US state where running a red light is a criminal offence instead of a civil offence.

CA SA LA 2002
The effect of 18 red-light cameras installed at nine junctions (two approaches at each junction) was compared with all other intersections in Los Angeles County, USA. The before period lasted 4.5 years, while the after period was two years. Camera sites were selected on the basis of red light running related crashes, right-angle crashes, traffic volumes, input from police and engineers and geographic distribution. Sites which required state highway authority approval were not chosen. Warning signs were installed at all camera junctions approaches. Results were limited to total crashes, including damage-only.

CA SA Oxnard 2002
Four red-light cameras were rotated between 11 junctions in Oxnard, California. Junctions were chosen on the basis of red-light related crash data, technical suitability and informal input, and compared with all other intersections. Camera sites were not restricted to the worst locations. The before period was 2.5 years, while the after period was four years. Warning signs were located at all major entrances to the city (but not at individual camera sites). Results were limited to total crashes, including damage-only.

CA SA Sacramento 2002
The effect of 10 red-light cameras rotated amongst 16 approaches at 11 junctions was compared to all other junctions in Sacramento, California. The before period lasted almost 4.5 years and the after period was two years. Camera sites were chosen on the basis of red light running related crashes, red-light violations, traffic volume, technical suitability, informal input, traffic police capacity, and geographic distribution. These included some sites that were not the most dangerous locations (three of 11 sites). Warning signs were originally placed at all major entrances (as allowed by state regulations) but additional signs were installed at all camera sites after a legal challenge. Results were limited to total crashes, including damage-only.

CA SA San Diego 2002
The impact of 19 red-light cameras at 19 sites was compared to all other junctions in San Diego, California. Camera sites were chosen on the basis of red-light running related crashes, red-light violations, informal input, and geographical distribution. Sites requiring state highway authority approval were avoided and five of the 19 sites selected were reported to be not among the worst locations. The before and after periods were each 3.5 years. Warning signs were located at all major entrances to the city (but not at camera sites). Results were limited to total crashes, including damage-only.

Effects of interventions

Total casualty crashes

The one study that adjusted for both spillover and RTM (Retting Oxnard 2002) had a rate ratio of 0.71 (95% CI 0.55 to 0.93). While the three studies that attempted to adjust for RTM (but not spillover) all had confidence intervals that included the value 1.0, their pooled rate ratio was 0.87 (95% CI 0.77 to 0.98) with no significant heterogeneity (P=0.60). Only one of the five non-adjusted studies reported on total casualty crashes and had a rate ratio of 0.80 (95% CI 0.58 to 1.12). Table 1

Right-angle casualty crashes

The only findings on right-angle and rear-end casualty crashes were from partially adjusted studies and studies with no adjustments. The pooled rate ratio of two (Ng Singapore 1997; South Melbourne 1988) of the three studies that partially adjusted for RTM was 0.76 (95% CI 0.54 to 1.07), with no signs of heterogeneity (P=0.24). The one (Mann Adelaide 1994) of the five unadjusted studies that reported on right-angle casualty crashes had a rate ratio of 0.74 (95% CI 0.39 to 1.44). Table 2 and Table 3

Rear-end casualty crashes

The pooled rate ratio from two (Ng Singapore 1997; South Melbourne 1988) of the three studies that partially adjusted for RTM was 0.82 (95% CI 0.50 to 1.34). There was no evidence of heterogeneity (P=0.16). Only one (Mann Adelaide 1994) of the six unadjusted studies reported on rear-end casualty crashes and had a rate ratio of 0.99 (95% CI 0.59 to 1.66). All three studies had confidence intervals that included 1.0. Table 4 and Table 5

Total crashes (including damage-only crashes)

For crashes of all severity, the study (Retting Oxnard 2002) that adjusted for both RTM and spillover reported a rate ratio of 0.93 (95% CI 0.83 to 1.05). Another study (Hillier Sydney 1993) that was partially adjusted had a rate ratio of 0.92 (95% CI 0.73 to 1.15). The pooled rate ratio of five unadjusted studies (CA SA LA 2002; CA SA Oxnard 2002; CA SA S'mento 2002; CA SA San Diego 2002; Mann Adelaide 1994) was 0.74 (95% CI 0.53 to 1.03) but three had confidence intervals that included 1.0. There was also significant evidence of heterogeneity (P=0.008). Table 6 and Table 7

Red-light violations

The one study (Ng Singapore 1997) that reported on the impact of red-light violations had a rate ratio of 0.53 (95% CI 0.17 to 1.66). Table 8

DISCUSSION

Red-light cameras have been shown to be effective in reducing total casualty crashes. The strongest evidence comes from a study that used gateway signing and did not install warning notices at camera sites, and whose evaluation included a comparison with nearby cities in order to adjust for spillover effects. This was the only study that accounted for both regression to mean and spillover effects.

The limited evidence available is less conclusive as to whether red-light cameras are able to reduce right-angle or rear-end casualty crashes or total crashes (including property damage only crashes) and traffic violations. The pooled rate ratios show that an overall reduction was achieved in these studies but the confidence intervals include the value 1.0, so the result could be explained by the play of chance. This is partially due to sample size as seen with the findings for total casualty crashes, where the pooled rate ratio of the three partially adjusted studies was reduced to 0.98. A meta-analysis is useful for comparing 'like with like' and, while the study findings for the three groups have been reported and thus can be compared, they have not been pooled to produce an overall estimate.

Although red-light cameras have been used for over 20 years, there have been very few studies meeting our inclusion criteria and the majority of these suffered from lack of adjustment for regression to mean and spillover effects. Included studies came from only three countries none of them in Europe, where red-light cameras have been used extensively. The most recent seven studies were from the US, six of which reported on total collisions only. This limits the strength as well as the transferability of the findings. Red-light cameras are beginning to be introduced in middle and low-income countries. The findings of studies from high-income countries cannot be assumed to apply to low and middle-income countries, especially as vehicle registration systems will be less developed, and owners and drivers less likely to be identified and have sanctions imposed.

Other systematic reviews have reported the difficulty of identifying intervention evaluations in road safety. The same problem was encountered in conducting this review. Many of the included studies, even those several years old, came from websites and from reading related material, and not from the literature search of the transport and public health databases.

AUTHORS' CONCLUSIONS

Implications for practice

The results show red-light cameras are effective in reducing total casualty crashes at signalised intersections. Policies on warning signs and camera site selection should aim to maximise the casualty reduction impact, including that at nearby non-camera sites, which may benefit from spillover effects.

Implications for research

Only ten evaluations met the inclusion criteria and their results were limited by methodological weaknesses with insufficient adjustment for regression to mean and spillover. Trials are needed which account for both these key factors and evaluate the impact of different signing policies (camera site specific or gateway approaches) and camera site selections (hazardous locations only or other concerns including geographic dispersion). Red-light camera approval procedures should also include proper monitoring and evaluation requirements.

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CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

CA SA LA 2002

Methods	CBA with minimum 4.5 year before period and minimum 14 month after period.
Participants	9 signalised junctions in Los Angeles County, USA.
Interventions	18 red-light cameras at 18 approaches, compared to all other Los Angeles intersections.
Outcomes	Impact on total crashes.

CA SA LA 2002 *(Continued)*

Notes	Warning signs at all camera site approached. Cameras installed at different times so adjusted monthly collision rate for 14 month before-after periods.

CA SA Oxnard 2002

Methods	CBA with at least 29 month before period and minimum 48 month after period.
Participants	11 signalised junctions in Oxnard, California, USA.
Interventions	4 red-light cameras rotated amongst 11 junctions and compared to non-signalised junctions in Oxnard.
Outcomes	Impact on total crashes.
Notes	Warning signs posted at major entrances to Oxnard but not at camera sites. Cameras installed at different times so adjusted monthly collision rate for 29 month before-after periods.

CA SA Sacramento 2002

Methods	CBA with minimum 53 month before period and minimum 14.5 month after period.
Participants	11 signalised junctions in Sacramento, California, USA.
Interventions	10 red-light cameras rotated amongst 16 approaches at 11 junctions and compared to all other junctions in Sacramento.
Outcomes	Impact on total crashes.
Notes	Warning signs posted at both major entrances and at camera sites. Cameras installed at different times so adjusted monthly collision rate for 14.5 before-after periods.

CA SA San Diego 2002

Methods	CBA with minimum 43 month before period and minimum 16 month after period.
Participants	19 signalised junctions in San Diego, California, USA.
Interventions	19 red-light cameras at 19 approaches at 19 sites compared to all other junctions in San Diego.
Outcomes	Impact on total crashes.
Notes	Warning signs posted at major entrances to city but not at camera sites. Cameras installed at different times so adjusted monthly collision rate for 16 before after periods.

Hillier Sydney 1993

Methods	CBA with 2-year before period and 2-year after period.

Hillier Sydney 1993 *(Continued)*

Participants	32 signalised junctions in Sydney, Australia.
Interventions	6 red-light cameras rotated amongst 16 signalised junctions.
Outcomes	Impact on total casualty crashes and specific types (right angle, right turn opposed and rear end crashes).
Notes	Study assumed no halo effect but could be due to warning signs; widespread publicity programme. Least used control sites had other improvements and so were disqualified.

Mann Adelaide 1994

Methods	CBA with 5-year before period and 5-year after period.
Participants	15 signalised junctions in Adelaide, Australia.
Interventions	5 red-light cameras rotated amongst 15 signalised junctions with high traffic volumes.
Outcomes	Impact on crashes by severity and collision type, and casualties.
Notes	Amber phase increased from 3 to 4 seconds at start of programme.

Ng Singapore 1997

Methods	CBA with 3-year before and 3-year after period.
Participants	84 signalised junctions in Singapore.
Interventions	42 red-light cameras and 42 comparison signalised junctions - all high-risk locations with similar layouts.
Outcomes	Impact on total casualty crashes and specific types (right angle, rear end, sideswipe/head-on, and all others).
Notes	RLC at 125 (20%) signalised junctions and warning signs posted at camera junction approaches.

Retting Fairfax 1999

Methods	CBA with after period of about 115 hours for RLC and 48-72 hours for control sites.
Participants	7 signalised junctions in Fairfax, Virginia, USA and 2 signalised junctions in nearlby counties.
Interventions	5 red-light cameras at signalised junctions.
Outcomes	Impact on red light violations.
Notes	Warning signs posted at major roads entering city.

Retting Oxnard 2002

Methods	CBA with camera warning signs posted.
Participants	City-wide comparison with Oxnard, USA (with red-light cameras) and three control cities without red-light cameras.
Interventions	Red-light cameras installed at 11 of 125 signalised junctions (2% of all signalised junction approaches) in camera city.
Outcomes	Impact on total crashes and total injury crashes and specific types (right angle and rear end - total and injury only).
Notes	Study assumed halo effect , no separate analysis of junctions (or approaches) equipped with cameras compared with other signalised junctions in same city. There was no other areawide road safety programme underway which might have contributed to the crash reduction.Fine was US$271 and 1 demerit point, fine had been substantially increased from $104 in January 1998.

South Melbourne 1988

Methods	CBA with 3-year before and 3-year after period.
Participants	Total of 98 signalised junctions divided into camera and control sites.
Interventions	Average of 7-19 cameras rotated amongs 46 camera sites.
Outcomes	Impact on casualty crashes including total, right angle and rear end types and total casualties.
Notes	Warning signs at all camera sites, camera and control sites evenly distributed.

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Andreassan 1995	Long-term study and controls did not account for other interventions. Red-light camera sites had few right-angle crashes.
CA SA Fremont 2002	Only 1 site with more than 1 year of after data.
CA San Francisco2002	Insufficient after data (no sites had 1 year of after data).
Charlotte NC 2003	3 year before-after data available on camera sites and camera approaches but not for comparison group. Citywide signalised junction data available but for red light running crashes only so no comparison possible to date.
Chen BC 2001	No contol studies and after data was from 1 and 6 months after camera installation.
Chin Singapore 1989	Before and after period only 1 month before and 1 month after camera installation and survey period only 1 day per site per period.
Hooke UK 1996	No control sites included in study. Also had problems getting casualty severity data and findings based on 20% sample (pg 27).
Howard Co Md 2003	No control sites.

Study	Reason for exclusion
ICBC Vancouver 2004	Insufficient data given on analysis method.
Lum Singapore 2002	Only 1 RLC site and no control period.
Mesa AZ 1999	Programme included both red light cameras and speed cameras.
NCHRP 2003	Insufficient data on RLC programmes in Mesa (Arizona), Polk County (Florida), San Francisco, Howard County (Maryland). Nor was more information available from their related websites
Polk Co FLA 2000	Only 1 year of after data.
Radalj Perth 2001	No base data provided on control.
Retting Oxnard 1999b	Evaluation conducted after only 4months.
SO Glasgow 1996	Only involved 2 red-light camerasand they were evaluated separately in areas.
Tarawneh 1999	Manual enforcement programme. No red-light cameras involved.
WA AG 1995	Insufficient information as red-light cameras were being introduced gradually and so difficult to identify how many active at time of evaluation. Also no data on crash histories of locations, or collision type or severity and after period appears too short for many red-light cameras.
Winn Strathclyde1995	Few (6) control sites, with 2 at camera junctions (but on non-camera approaches). Limited no. after hours monitoring (19).

DATA AND ANALYSES

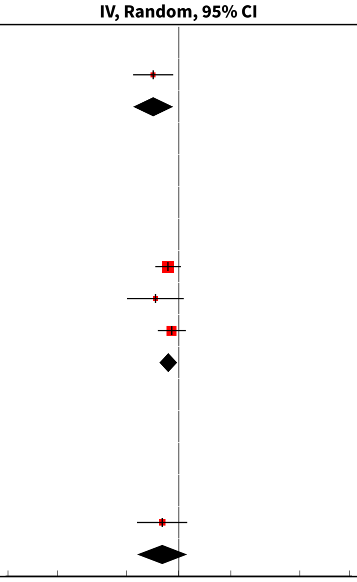
Comparison 1. Red light cameras vs controls

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 Total casualty crashes	5		Rate ratio (Random, 95% CI)	0.84 [0.76, 0.93]
1.1 Adjusted studies	1		Rate ratio (Random, 95% CI)	0.71 [0.55, 0.93]
1.2 Partially adjusted	3		Rate ratio (Random, 95% CI)	0.87 [0.77, 0.98]
1.3 No adjustments	1		Rate ratio (Random, 95% CI)	0.80 [0.58, 1.12]
2 Right angle casualty crashes	3		Rate ratio (Random, 95% CI)	0.76 [0.58, 0.99]

Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
2.1 Partially adjusted studies	2		Rate ratio (Random, 95% CI)	0.76 [0.54, 1.07]
2.2 No adjustments	1		Rate ratio (Random, 95% CI)	0.74 [0.39, 1.44]
3 Rear end casualty crashes	3		Rate ratio (Random, 95% CI)	0.87 [0.63, 1.19]
3.1 Partially adjusted studies	2		Rate ratio (Random, 95% CI)	0.82 [0.50, 1.34]
3.2 No adjustments	1		Rate ratio (Random, 95% CI)	0.99 [0.59, 1.66]
4 Total crashes (including damage only)	7		Rate ratio (Random, 95% CI)	0.85 [0.73, 0.99]
4.1 Adjusted studies	1		Rate ratio (Random, 95% CI)	0.93 [0.83, 1.05]
4.2 Partially adjusted studies	1		Rate ratio (Random, 95% CI)	0.92 [0.73, 1.15]
4.3 No adjustments	5		Rate ratio (Random, 95% CI)	0.74 [0.53, 1.03]

Analysis 1.1. Comparison 1 Red light cameras vs controls, Outcome 1 Total casualty crashes.

Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
1.1.1 Adjusted studies						
Retting Oxnard 2002	1	1	-0.3 (0.136)		14.89%	0.71[0.55,0.93]
Subtotal (95% CI)					**14.89%**	**0.71[0.55,0.93]**
Heterogeneity: Not applicable						
Test for overall effect: Z=2.49(P=0.01)						
1.1.2 Partially adjusted						
South Melbourne 1988	1	1	-0.1 (0.086)		37.44%	0.87[0.73,1.03]
Hillier Sydney 1993	1	1	-0.3 (0.194)		7.34%	0.73[0.5,1.07]
Ng Singapore 1997	1	1	-0.1 (0.094)		30.92%	0.91[0.76,1.1]
Subtotal (95% CI)					**75.71%**	**0.87[0.77,0.98]**
Heterogeneity: Tau²=0; Chi²=1.01, df=2(P=0.6); I²=0%						
Test for overall effect: Z=2.29(P=0.02)						
1.1.3 No adjustments						
Mann Adelaide 1994	1	1	-0.2 (0.171)		9.4%	0.8[0.58,1.12]
Subtotal (95% CI)					**9.4%**	**0.8[0.58,1.12]**



Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
Heterogeneity: Not applicable						
Test for overall effect: Z=1.28(P=0.2)						
Total (95% CI)					**100%**	**0.84[0.76,0.93]**
Heterogeneity: Tau²=0; Chi²=2.9, df=4(P=0.58); I²=0%						
Test for overall effect: Z=3.35(P=0)						
Test for subgroup differences: Chi²=1.89, df=1 (P=0.39), I²=0%						

Favours treatment 0.1 0.2 0.5 1 2 5 10 Favours control

Analysis 1.2. Comparison 1 Red light cameras vs controls, Outcome 2 Right angle casualty crashes.

Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
1.2.1 Partially adjusted studies						
South Melbourne 1988	1	1	-0.5 (0.217)		39.74%	0.63[0.41,0.97]
Ng Singapore 1997	1	1	-0.1 (0.207)		43.63%	0.9[0.6,1.35]
Subtotal (95% CI)					**83.37%**	**0.76[0.54,1.07]**
Heterogeneity: Tau²=0.02; Chi²=1.4, df=1(P=0.24); I²=28.53%						
Test for overall effect: Z=1.56(P=0.12)						
1.2.2 No adjustments						
Mann Adelaide 1994	1	1	-0.3 (0.336)		16.63%	0.74[0.39,1.44]
Subtotal (95% CI)					**16.63%**	**0.74[0.39,1.44]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.88(P=0.38)						
Total (95% CI)					**100%**	**0.76[0.58,0.99]**
Heterogeneity: Tau²=0; Chi²=1.4, df=2(P=0.5); I²=0%						
Test for overall effect: Z=2.03(P=0.04)						
Test for subgroup differences: Chi²=0, df=1 (P=0.96), I²=0%						

Favours treatment 0.1 0.2 0.5 1 2 5 10 Favours control

Analysis 1.3. Comparison 1 Red light cameras vs controls, Outcome 3 Rear end casualty crashes.

Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
1.3.1 Partially adjusted studies						
South Melbourne 1988	1	1	-0.4 (0.244)		35.99%	0.64[0.4,1.04]
Ng Singapore 1997	1	1	0.1 (0.26)		32.3%	1.06[0.64,1.77]
Subtotal (95% CI)					**68.28%**	**0.82[0.5,1.34]**
Heterogeneity: Tau²=0.06; Chi²=1.99, df=1(P=0.16); I²=49.67%						
Test for overall effect: Z=0.79(P=0.43)						
1.3.2 No adjustments						

Favours treatment 0.1 0.2 0.5 1 2 5 10 Favours control

Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
Mann Adelaide 1994	1	1	-0 (0.263)		31.72%	0.99[0.59,1.66]
Subtotal (95% CI)					**31.72%**	**0.99[0.59,1.66]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.04(P=0.97)						
Total (95% CI)					**100%**	**0.87[0.63,1.19]**
Heterogeneity: Tau²=0.01; Chi²=2.37, df=2(P=0.31); I²=15.69%						
Test for overall effect: Z=0.89(P=0.37)						
Test for subgroup differences: Chi²=0.27, df=1 (P=0.6), I²=0%						
			Favours treatment	0.1 0.2 0.5 1 2 5 10	Favours control	

Analysis 1.4. Comparison 1 Red light cameras vs controls, Outcome 4 Total crashes (including damage only).

Study or subgroup	Red light camera N	Control N	log[Rate ratio] (SE)	Rate ratio IV, Random, 95% CI	Weight	Rate ratio IV, Random, 95% CI
1.4.1 Adjusted studies						
Retting Oxnard 2002	1	1	-0.1 (0.06)		26.86%	0.93[0.83,1.05]
Subtotal (95% CI)					**26.86%**	**0.93[0.83,1.05]**
Heterogeneity: Not applicable						
Test for overall effect: Z=1.22(P=0.22)						
1.4.2 Partially adjusted studies						
Hillier Sydney 1993	1	1	-0.1 (0.114)		18.93%	0.92[0.73,1.15]
Subtotal (95% CI)					**18.93%**	**0.92[0.73,1.15]**
Heterogeneity: Not applicable						
Test for overall effect: Z=0.74(P=0.46)						
1.4.3 No adjustments						
Mann Adelaide 1994	1	1	0 (0.072)		25.08%	1.02[0.88,1.17]
CA SA LA 2002	1	1	-0.3 (0.331)		4.72%	0.73[0.38,1.4]
CA SA Oxnard 2002	1	1	-0.6 (0.215)		9.31%	0.52[0.34,0.8]
CA SA Sacramento 2002	1	1	-0.6 (0.235)		8.19%	0.56[0.35,0.88]
CA SA San Diego 2002	1	1	-0.1 (0.262)		6.91%	0.91[0.54,1.52]
Subtotal (95% CI)					**54.21%**	**0.74[0.53,1.03]**
Heterogeneity: Tau²=0.09; Chi²=13.79, df=4(P=0.01); I²=71%						
Test for overall effect: Z=1.79(P=0.07)						
Total (95% CI)					**100%**	**0.85[0.73,0.99]**
Heterogeneity: Tau²=0.02; Chi²=13.89, df=6(P=0.03); I²=56.8%						
Test for overall effect: Z=2.06(P=0.04)						
Test for subgroup differences: Chi²=1.64, df=1 (P=0.44), I²=0%						
			Favours treatment	0.1 0.2 0.5 1 2 5 10	Favours control	

ADDITIONAL TABLES

Table 1. Total casualty crashes

Study ID	RLC before	RLC after	Control before	Control after	Rate ratios	95% CIs
South Melbourne 1988	596	450	625	544	0.867	(0.733,1.026)
Hillier Sydney 1993	127	82	123	108	0.735	(0.503,1.075)
Mann Adelaide 1994	147	86	220	160	0.804	(0.575,1.125)
Ng Singapore 1997	520	386	510	415	0.912	(0.758,1.097)
Retting Oxnard 2002	299	239	173	194	0.713	(0.546,0.930)

Table 2. Right angle casualty crashes

Study ID	RLC before	RLC after	Control before	Control after	Rate ratios	95% CI
South Melbourne 1988	123	48	144	89	0.631	(0.413,0.966)
Mann Adelaide 1994	63	29	42	26	0.744	(0.385,1.435)
Ng Singapore 1997	107.5	79.4	105.4	86.5	.900	(0.599,1.350)

Table 3. Total right angle crashes (including damage only)

Study ID	RLC before	RLC after	Control before	Control after	Rate ratios	95% CI
Hillier Sydney 1993	141	59	94	50	0.787	(0.497,1.244)
Mann Adelaide 1994	132	97	184	125	1.082	(0.765,1.530)

Table 4. Rear end casualty crashes

Study ID	RLC before	RLC after	Control before	Control after	Rate ratios	95% CI
South Melbourne 1988	68	63	59	85	0.643	(0.399,1.036)
Mann Adelaide 1994	47	34	130	95	0.990	(0.592,1.656)
Ng Singapore 1997	73	57	66	48	1.062	(0.638,1.766)

Table 5. Total rear end crashes (inc damage only)

Study id	RLC before	RLC after	Control before	Control after	Rate ratios	95% CIs
Hillier Sydney 1993	64	103	75	58	2.081	(01.309, 3.308)
Mann Adelaide 1994	360	377	784	730	1.125	(0.943, 1.341)

Table 6. Total crashes (including damage only)

Study ID	RLC before	RLC after	Control before	Control after	Rate ratios	95% CI
Hillier Sydney 1993	383	267	348	264	0.919	(0.735,1.149)
Mann Adelaide 1994	623	598	1095	1033	1.017	(0.884,1.171)
Retting Oxnard 2002	1322	1250	2583	2577	0.930	(0.827,1.045)
CA SA LA 2002	16	23	827	853	0.730	(0.382,1.396)
CA SA Oxnard 2002	35	79	360	421	0.524	(0.344,5.799)
CA SA Sacramento 2002	30	54	693	693	0.558	(0.352,0.884)
CA SA San Diego 2002	28	33	739	800	0.909	(0.544,1.519)

Table 7. Property damage only crashes

Study Id	RLC before	RLC after	Control before	Control after	Rate ratios	95% CI
Mann Adelaide 1994	476	512	875	873	1.078	(0.922,1.260)
Retting Oxnard 2002	1023	1011	821	817	0.993	(0.872,1.131)

Table 8. Red light violations

Study ID	RLC before	RLC after	Control before	Control after	Relative risk	95% CI
Retting Oxnard 1999b	36.3	20.4	7.6	8.0	0.534	(0.172,1.655)

APPENDICES

Appendix 1. Search strategy

Cochrane Injuries Group's Specialised Register and **MEDLINE** (1966-2002/05)

No.	search	No. records found
1	Red light near camera*	7
2	Red light near running	19
3	Traffic near camera*	4
4	Intersection near camera*	4
5	Junction near camera*	9
6	Photo* near enforc*	7
7	Automat* near camera*	132
8	Traffic near violation*	100
9	5 or 4 or 3 or 2 or 1 or 8 or 7 or 6	276

EMBASE 1980-July week 3 2002

No.	search	No. records found
1	red light camera.mp	2
2	red light running.mp	2
3	(traffic adj5 camera$).mp	2
4	(intersection adj5 camera$).mp	3
5	(junction adj5 camera$).mp	4
6	(photo$ adj5 enforc$).mp	4
7	(automat$ adj5 enforc$).mp	5
8	1 or 2 or 3 or 4 or 5 or 6 or 7	19

Transport 1988-2002/6

No.	search	no. records found
1	Red light camera*	102

(Continued)

2	Red light running	95
3	Traffic near camera*	509
4	Intersection near camera*	38
5	Junction near camera*	5
6	Photo* near enforc*	76
7	Automat* near enforc*	253
8	1 or 2 or 3 or 4 or 5 or 6 or 7	877
9	crash* or injur* or fatal* or death or collision* or violation* or accident*	41595
10	8 or 9	379

Australian Transport Index (ATRI) (Webspirs) 1976-July 2002

No.	search	No. records found
1	Red light camera*	101
2	Red light running	27
3	Traffic near camera*	53
4	Automat* near enforc*	38
5	Intersection near camera*	5
6	Junction near camera*	2
7	1 or 2 or 3 or 4 or 5 or 6	186
8	Crash* or injur* or fatal* or death or collision* or violation* or accident* or enforc*	26621
9	2 or 8	26628
10	7 and 9	151

WHAT'S NEW

Date	Event	Description
14 March 2012	Amended	Additional tables linked to text.

HISTORY

Protocol first published: Issue 4, 2002
Review first published: Issue 2, 2005

Date	Event	Description
11 September 2008	Amended	Converted to new review format.

CONTRIBUTIONS OF AUTHORS

AAT had the lead in designing the protocol, screening records (titles and abstracts), obtaining reports, extracting data and writing the review. SH contributed with screening records (titles and abstracs), obtaining reports, extracting and analysing data, and editing drafts of the review.

DECLARATIONS OF INTEREST

None known.

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INDEX TERMS

Medical Subject Headings (MeSH)

Accident Prevention [instrumentation] [*methods]; Accidents, Traffic [*prevention & control]; Controlled Clinical Trials as Topic; Photography [instrumentation] [*methods]

MeSH check words

Humans